Wave Data Processing and Analysis Tools for Developing Wave Boundary Forcing for CMS-Wave and GenCade Numerical Models: Part 1

US Army Corps of Engineers®

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PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) presents a collection of wave data processing and analysis tools for assimilating measured wave data into wave climatology statistics and representative data subsets. These representative data subsets can be applied to force the offshore boundary of numerical wave models and also provide general wave climatology analysis. This CHETN focuses on applications employing the numerical models CMS-Wave (Lin et al. 2008) and GenCade (Frey et al. 2012); however, the toolkit has been developed with substantial flexibility such that it can be readily modified for other models or analyses. The CHETN first describes the data processing tools and then presents an example application. The general work-flow process, specific inputs, execution steps, and resulting outputs are described through the example application. The toolkit and the example dataset discussed herein can be downloaded from *http://cirp.usace.army.mil/products/?tab=4*.

DESCRIPTION OF TOOLKIT: The wave data processing toolkit was developed to operate in the MATLAB® environment (2007 or later) with the exception of the final step of CMS-Wave-to-GenCade map file conversion which was developed in Fortran. The toolkit consists of three MATLAB m-files (*.m) and one Windows Fortran executable, which is discussed in a second technical note (Permenter et al. 2013):

- **JP_BinWaves.m:** This is the main code and includes input options, calls to the other functions, the main probability histogram binning routine, tabular output commands, and graphical data output plots.

- **Linwavetheory.m:** This function calculates the linear wave theory transformation and output and calls wavdisp_eq.m function.

- **Wavdispeq.m:** This function calculates the dispersion equation using the Newton-Raphson method for convergence.

The toolkit process assumes the user has downloaded a long-term, time series wave dataset in a text file (*.txt or *.dat) in meters and meteorological wave direction convention. These data were then imported into MATLAB and processed and analyzed during the execution of JP_WaveBin.m. The tool accepts input through a series of command prompt questions in order to determine the desired wave binning strategy.

The code filters the data and then bins the data to develop a 3-way (significant wave height [H_s] vs. wave period [T] vs. wave directions [Dir]) joint probability (*JP*). The code also allows for seasonal

			Form Approved OMB No. 0704-0188

1. REPORT DATE **SEP 2013**	2. REPORT TYPE	3. DATES COVERED **00-00-2013 to 00-00-2013**

4. TITLE AND SUBTITLE **Wave Data Processing and Analysis Tools for Developing Wave Boundary Forcing for CMS-Wave and GenCade Numerical Models: Part 1**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **US Army Engineer Research and Development Center (ERDC),Coastal and Hydraulics Laboratory (CHL),Vicksburg,MS,39180**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**10**	

binning of the time series by evenly dividing each year into a given number of time bins. Tables for two-way *JP* are written as output for comparison of H_s vs. *T*, H_s vs. *Dir*, and *T* vs. *Dir*. The two-way *JP* tables may be used for developing wave roses using the bin definitions, the bin data (for H_s, *T*, and *Dir*), and the percent occurrence (or the number of occurrences).

The user defines the input bins for H_s, *T*, and *Dir*. Similarly, the user may define maximum and minimum values for wave parameters (e.g., only include events with H_s above 3 m or disregard all wave events with *T* less than 4 sec; or H_s less than 0.25 m, etc.) to remove outliers or flags in the input dataset. The code generates an output file containing the percent occurrence for each time division for each binned wave condition. The code divides each year of the time series into equally spaced intervals to allow for characterization of seasonal variability in the input wave time series. The user specifies the number of seasonal bins used (1 for no binning, 12 for monthly). The number of occurrences for each height, period, and direction combination is calculated for each seasonal bin for the entire length of the input dataset (an event in February 1991 will have the same effects as an equivalent event in February 1995). Each row in the output file represents one binned condition, while the columns represent the seasonal bins. In addition to the JP table output, output also includes general wave statistics (Mean significant wave height, Mean peak Period, Standard Deviation, Maximum significant wave height, Minimum significant wave height, and Period and Direction associated with maximum significant wave height) and a file containing the wave index, height, period, direction, number of occurrences, and percent occurrences for each binned wave condition without seasonal binning. The index for each wave condition is represented by the following formula:

$$Index\ of\ Event = Index\ of\ H\ Bin * 10000 + Index\ of\ T\ Bin * 100 + Index\ of\ D\ Bin$$

The user must use the SMS interface to create a *.eng file in order to run CMS-Wave. The table listed in the WaveBin_Table_Over_MinCount_Threshold.dat output file must be copied into the spectra generator within CMS-Wave. This process will be detailed in CHETN-IV-98. The *.eng file supplies the offshore wave spectra for the CMS-Wave runs (Lin et al. 2008). The CMS2MAP executable takes the CMS-Wave output files and produces a *.map or *.gen file for input into GENCADE. Features of the wave data processing toolkit are presented below in an example application following step-by-step instructions with comments to guide users.

EXAMPLE: Wave Information for Ship Island, Mississippi. This example demonstrates use of the wave data processing toolkit to transform offshore wave data to the model boundary, calculate the wave data statistics, and produce the input data files for wave models. For this example the user has saved a 20-year wave time series from WIS station 144 at a depth of 16 m. The user executes **JP_BinWaves.m** in order to transform the waves to the offshore boundary of a CMS-Wave grid and bin the data. The user then wishes to develop boundary wave forcing which characterizes the 20-year time series into a manageable set of steady-state forcing parameters, which will be converted to input wave energy spectra. Note that the code is developed for metric units with wave angles in degrees and conforming to meteorological direction convention. The toolkit files and Ship Island example datasets may be downloaded from *http://cirp.usace.army.mil/ products/?tab=4*.

Input of Wave Information.

Step 1. Save the toolkit MATLAB m-files and offshore wave data into the same working directory.

Step 2. Launch MATLAB and execute **JP_BinWaves.m** by typing "JP_BinWaves" at the command prompt. The following is the command prompt when the user executes the main script:

>>>*JP_BinWaves*

Step 3. Executing the MATLAB script initially opens a dialogue window that gives the user the opportunity to browse for and select the wave input file. The file should be in either an ASCII *.txt or *.dat format. When it is selected, the user selects *<OK>* and the data file is loaded into MATLAB.

Step 4. The user is prompted to input the file column delimiter. In this example, the file was space delimited:

Enter wave data file column delimiter [space]:
< > for space, <,> for comma, <\t> for tab, <enter_delimiter_character(s)_here> for custom:

>>>

Step 5. The user is prompted to input the number of header rows (if any). In this example, there was one header row:

Enter number of header rows in wave data file [default = 0]:
>>> 1

Setting wavedata_delimiter to default space delimited.
Number of Header Rows in Wave Data File:
1

Step 6. The user is prompted to input the column numbers associated with the height, period, and direction as well as the data input type and number of seasonal bins. The seasonal binning is performed by evenly dividing the year into the desired number of bins and determining the percent occurrence of each binned event in each seasonal bin. The data input type is used to determine which columns in the data file signify the date stamps (YYYYMMDDHHMMSS is the first column in WIS). This step provides flexibility to change format of the input data. In this example, columns 10, 11, and 16 represent H_s, T, and *Dir*, respectively, a WIS data file is utilized, and 12 seasonal bins are specified:

Enter column number for Significant Wave Height (H_s):
>>> 10
Enter column number for Wave Period (T):
>>> 11
Enter column number for Wave Direction (Dir):

>>> *16*
Enter input type (1 for NDBC buoy, 2 for WIS Data file):
>>> *2*
Enter number of seasonal periods for binning:
>>> *12*

Step 7. At this point, the program reads the data file into MATLAB.

Transformation to a CMS-Wave Offshore Boundary.

Step 1. First, the user is prompted to make a decision on whether or not to apply a linear wave transformation from a distant offshore data point to the shallower and further inshore wave model boundary. In cases where the user wishes to simply process and analyze the data directly from the source, wave transformation may not be necessary or desired. However, if the user wishes to translate waves from a buoy (or hindcast station) that is not located at the offshore boundary of the wave model grid, it is recommended that a linear transformation be applied prior to continuing with the analysis. In this example, the user requests linear wave transformation to shallower water:

Perform Linear Wave Transformation Routine (Snell's Law) <Y/[N]>?
>>> *y*

Step 2. The user is prompted to input the depth of the offshore input wave information and the desired target depth to transform the waves. In this example, the offshore depth at WIS 144 is 16 m and the target depth of the offshore boundary of the CMS-Wave grid is 12 m:

Enter input wave information depth (m):
>>> *16*

Enter target wave station depth to transform waves to (m):
>>>*12*

Step 3. The user is prompted to convert the wave angle from meteorological to shore normal. In order to use the linear wave transformation code, the waves must be between -90 and 90 degrees relative to shore normal (Figure 1).

Step 4. The user is prompted to enter the wave angle of the shore-normal reference:

Enter shore normal reference angle (e.g., 270 = west facing coast; 0 = north facing coast; 90 = east facing coast; 180 = south facing coast):
>>> *161.3*

Step 5. The user is prompted to enter cutoff values for both the wave height and wave period to discard outliers and flags for missing data. Any direction values greater than 90 or less than -90 will be automatically discarded at this point.

Enter threshold of maximum wave height:
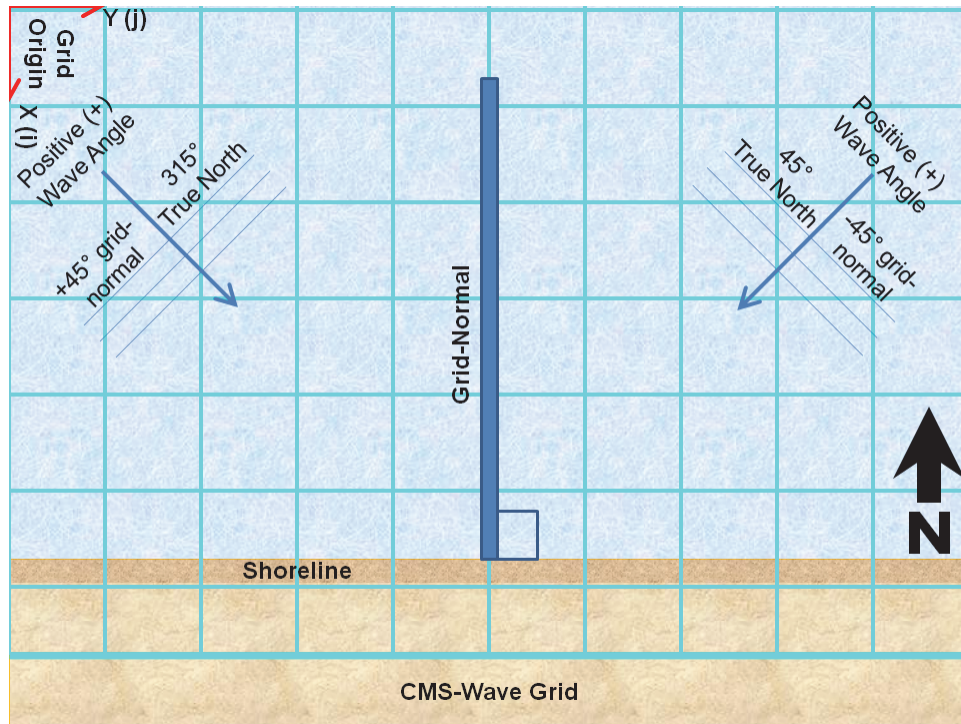*(all H values greater than this threshold will be reset to NaN)*
>>> *25*

Figure 1.   Shore Normal Wave Convention

Wave Heights > 25 have been reset to NaN!
Enter threshold of maximum wave period:
(all T values greater than this threshold will be reset to NaN)
>>> 20
Wave Period > 20 have been reset to NaN!
Wave Angles > 90 have been reset to NaN!
Wave Angles <-90 have been reset to NaN!

Step 6. After the angles are converted to shore-normal reference system, the linear wave transformation routine is executed. This is where the call to linwavetheory.m is executed:

Continue with calculations? <Y/[N]>
>>> y

Step 7. Next, the call to wavdispeq.m is automatically executed from within the linwavetheory.m function in order to calculate the wave number (k) at the target station depth.

Step 8. Finally, the wave transformation is complete and the routine automatically proceeds to the next step: histogram bin sorting of the waves and calculating mean conditions of the population in each bin.

Time Series Conversion to Representative Wave Forcing.

Step 1. The user is now prompted to select which method to apply to define the histogram binning scheme. The first option is to input band widths and auto-bin between minimum and maximum

data values. If the range of data does not come to an even number of bins, the last bin contains the data from the end of the previous bin to the maximum data value. For the second method the user inputs a bracketed series of the bin edges for *H*, *T*, and *Direction* (e.g., [-90 -60 -30 -15 15 30 60 90]). In this example, the default method (method 1) is selected such that the user may define the bin width for auto-binning between min and max data values:

> *Enter input method to define bin edges (Input <[1], 2>):1*
>
> *Input band widths for auto-binning between min and max data values; Enter 1:*
> *Input explicit array of bin edges; Enter 2:*
>
> *>>> 1*

In this example, significant wave height is binned in 0.5-m increments; wave period bins in 2 sec increments; and wave-angle bins ranging from - 10-deg increments.

> *Enter user-specified wave height band width (e.g., 0.5) : .5*
> *Enter user-specified wave period band width (e.g., 2) : 2*
> *Enter user-specified wave angle band width (e.g., 10) : 10*

Step 2. The histogram bin scheme is echoed back to the screen so that the user may review the calculated bin scheme based on the user-defined bin bounds.

Step 3. Finally, the main loop is executed and the data were binned into each user-defined histogram bin by frequency of occurrence of each permutation.

Step 4. An option allows the user to reduce the number of permutations for modeling by ignoring permutations that fall below a minimum count threshold. In this example, the user decides to include every permutation occurring:

> *Enter minimum count (occurrence) threshold to consider for output table <[1]>:*
> *>>> 1*

Step 5. After the main binning loop is complete, a series of ASCII output tables reporting results of the data processing executed by the script were written to output files in the working directory and include the following seven files:

- WaveBin_table.dat: Wave bin 3-way joint probability permutation table
- WaveBin_ table_Over_MinCount_Threshold.dat: Wave bin permutation table eliminating values less than the minimum count threshold
- WaveStats_table.dat: Wave data bulk statistics table
- JP_HvsT_table.dat: Significant wave height vs. period 2-way joint probability table
- JP_DvsH_table.dat: Wave direction vs. significant wave height 2-way joint probability table
- JP_TvsD_table.dat: Wave period vs. direction 2-way joint probability table
- JP_MultipleTimebin_Probability.dat: Wave Permutation table with Seasonal Bins

Step 6. Finally, a series of figures representing the data processing executed by the script are automatically plotted as output. These figures include stacked histogram plots that show the

probability distribution of each two-way joint probability result for the binned significant wave height, period, and direction; 3-dimensional (3D) surface histogram plots that show the probability distribution of each 2-way result for H_s vs. T (demonstrated for the example case in Figure 2), wave angle to H_s, and T to wave angle; and, a 2D probability plot of H_s vs. T.
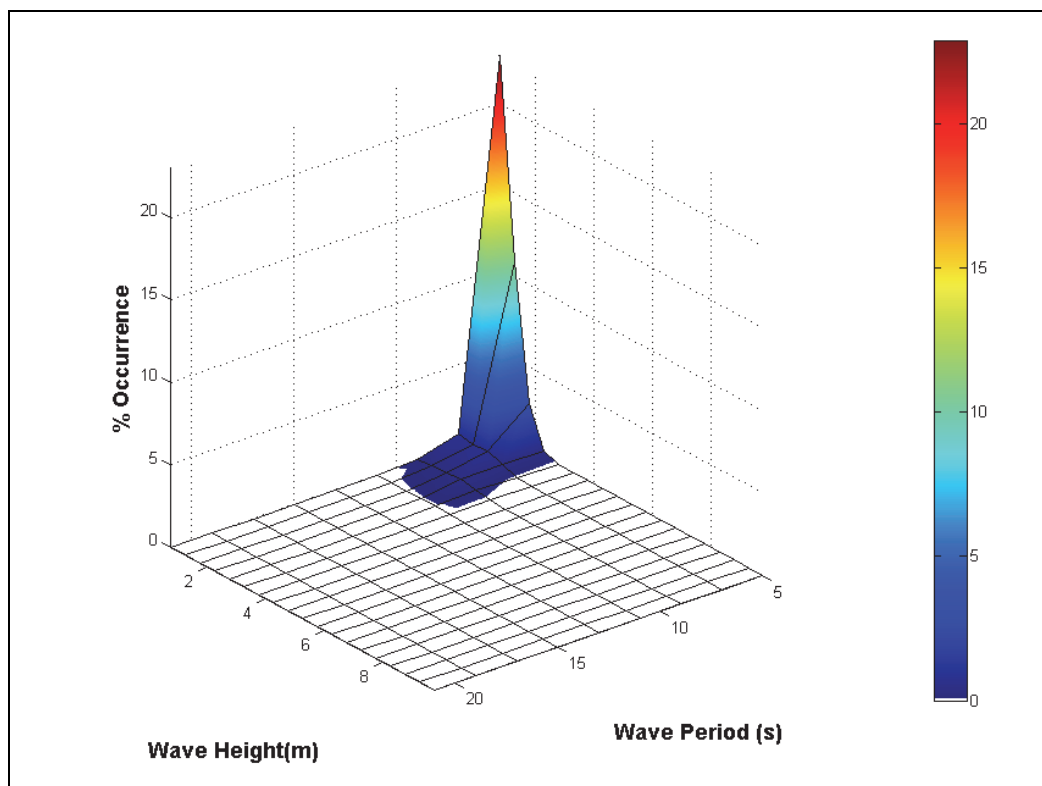

Figure 2.   Percent Occurrence for Wave Height vs. Wave Period

At this stage, the user is prompted on whether to plot the polar axis of the wave rose as referencing frequency in counts or frequency by percent (%) occurrence. Percent occurrence is the default option:

> *Enter 1 to plot frequency in counts or Enter 2 to plot % Occurrence, [2]:*
> *>>> 2*
>
> *Plotting frequency in % Occurrence*
> *You entered: 2*

Next, a wave rose is developed and plotted as shown in Figure 3. It is important to note that the wave directions are referenced to shore normal and therefore fall between -90 deg and +90 deg. The polar axis may be rotated to any angle with minimal effort within MATLAB. Finally, figures are presented to show the percent (%) exceedance vs. percent (%) occurrence at each bin for significant wave height, period, and direction, respectively. The % exceedance does not always reach 100% because the analysis ignored some of the data beyond the thresholds applied by the user.
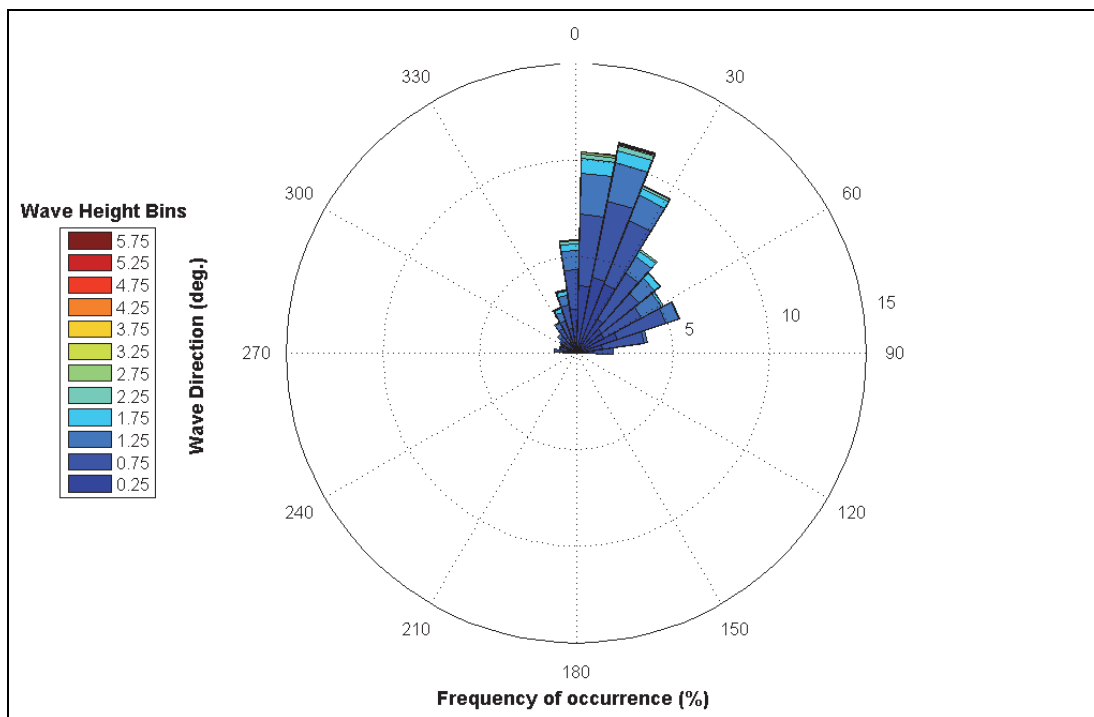
Figure 3. Wave Direction

SUMMARY: This CHETN describes a suite of tools to develop wave statistics and representative wave-climate datasets for application as wave forcing at offshore boundaries for numerical models. This CHETN is the first of a two-part series discussing the binning of wave conditions for use in CMS-Wave (or other spectral wave models such as STWAVE). The second CHETN will discuss importing wave conditions into CMS-Wave and using CMS-Wave output as input wave forcing in GenCade. Long-term wave information from hindcast databases or measured wave information may be analyzed using the tools described herein to develop representative wave climate statistics. These results are applied as boundary forcing to numerical models for additional wave transformation and as input to predictive tools for calculating coastal processes. These tools may be used as a means of converting measured waves and model solutions to manageable model input files. These tools will be further developed and integrated with existing models and GUIs. Guidance is anticipated to change following publication; the user is directed to the Coastal Inlets Research Program (CIRP) website (*cirp.usace.army.mil*) and the CIRP wiki (*cirp.usace. army.mil/wiki*).

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Connell, K. J., and R. Permenter. 2013. *Wave data processing and analysis tools for developing wave boundary forcing for CMS-Wave and GenCade numerical models: Part 1*. ERDC/CHL CHETN-IV-97. Vicksburg, MS: US Army Engineer Research and Development Center.

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